Lab Assignment 1

Tolerance Assigning, Machining and Testing of a Two-Part Assembly

ENGR 3350.203 – Manufacturing Processes

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Team 17

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ABSTRACT:

Two pieces of 6061-T6 Aluminum were used for this project. The objective of the lab was to build an assembly that was able to withstand a 10 ft-lb$_f$ torque applied at the end of the shaft without turning. It was necessary to follow the guideline dimensions which are provided in the theory section. Also, it was necessary to consider the tolerances and use three important manufacturing processes: cutting, milling, and drilling. A band saw, a milling machine, and a lathe were employed to accomplish this. In optimal conditions, the contact pressure wouldn't exceed the yield strength of the material we used. Though the assembly passed the test, it sustained more contact pressure than anticipated. Further investigation may need to be done into the implications of this.

INTRODUCTION:

The objectives of this experiment were to create an assembly meeting given specifications, as well as to test the capability of the interference fit used to secure the two pieces together. Interference fits, or press fits, are common means of combining independent parts. The testing of the assembly was of paramount importance to product creation. Discovering the product is defective through experimentation is cheaper and potentially less destructive than learning of its deficiencies after installation into a more extensive system.

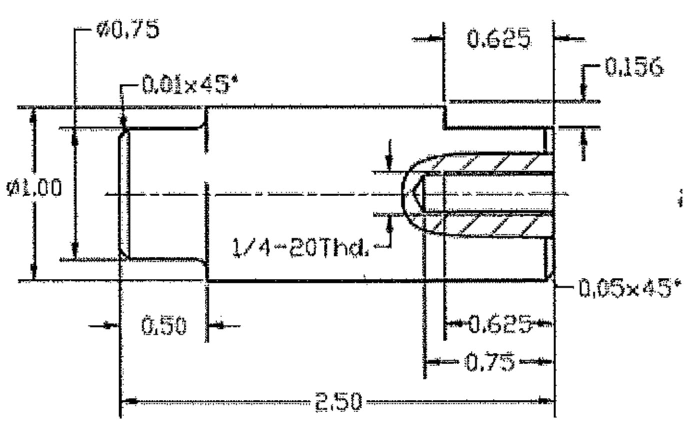
THEORY:

Figures 1 and 2 below show the mechanical drawings that were used as guidelines for machining. To manufacture the shaft and the plate, it was required to pay close attention to the measurements and tolerances of the drawings. Figures 3 and 4 give us, respectively, the side and isometric view of the assembly. Both views helped to visualize the projection of the assembly.

It was assumed that the square plate had a length of 3.00, so for considering the significant figures, we can assume that the tolerance is ±0.005. Also, in the process of machining the part, we assumed that no chips would interfere with the cutting process or affect the smoothness of the cuts. It was assumed that no chatter would occur. An equation that was very helpful for this experiment was the contact pressure equation, using interference values. This equation can be used since the shaft and the plate are made of the same material (6061-T6 Aluminum).

$$P = \frac{E\delta}{2d^3}\left[\frac{(d_o^2-d^2)(d^2-d_i^2)}{d_o^2-d_i^2}\right] \tag{1}$$

Where P is the contact pressure, $\delta$is the interference, d is the shaft diameter, d This equation is used when the shaft and the plate are made of the same material. Above formula came from Budynas [1].



[1]

Figure 1. Aluminum shaft dimension

[1] Mechanical drawing on pages 2-3 came from Carlson [2]

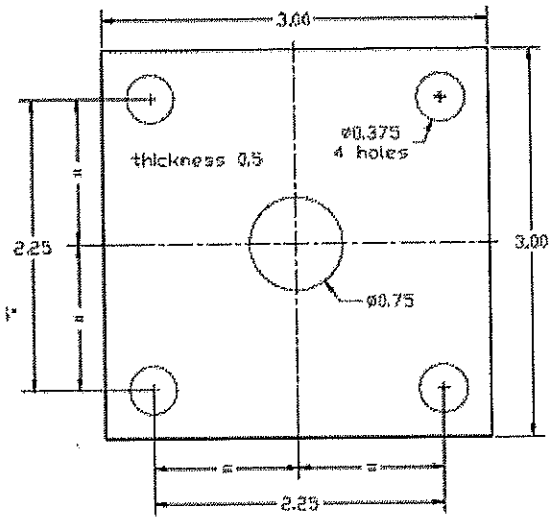


Figure 2. Aluminum plate dimensions

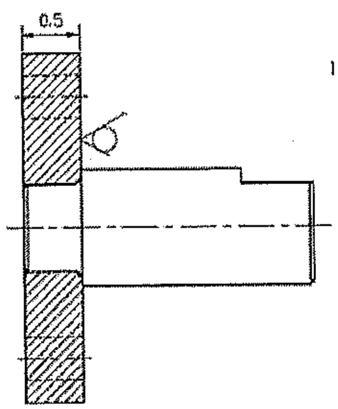


Figure 3. Side sectional view of desired final assembly

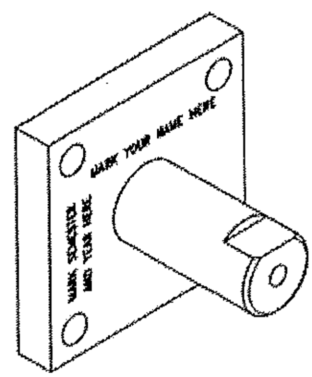
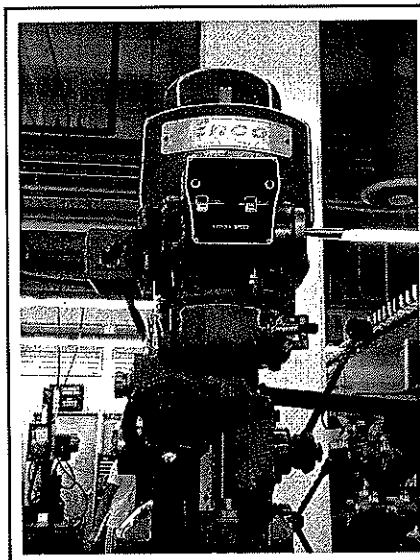


Figure 4. Isometric view of desired final assembly

EQUIPMENT:

MetalMizer Band Saw*	
Model	MS2018-1
Kerf	⅛ in.
Figure 5. Used to cut round stock and flat bar.	

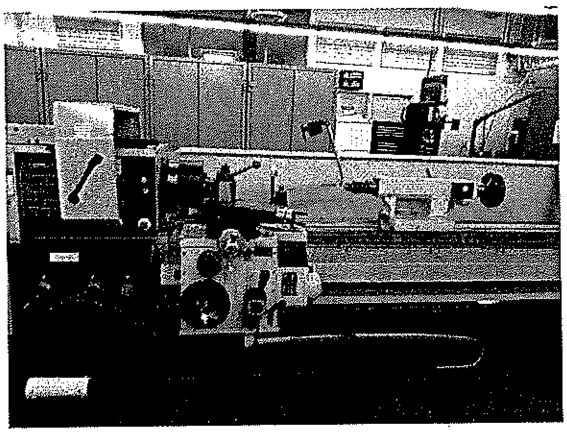


Enco Milling Machine*	
Model	X06323
Min. Measurement Dimensions	1/1000 in.
Figure 6. Used to machine and face off sides of the plate. It was used along a ¾" diameter end mill.	

Bridgeport Milling Machine*	
S/N	HDNG3377
Min. Measurement Dimensions	1/1000 in.

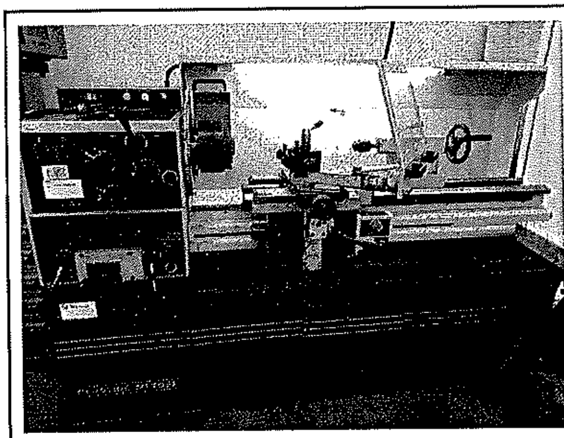
Figure 7. Used to drill holes on plate. It was used along the following accessories:

- Center hole: ¾" ~~drill bit~~ end mill
- Corner holes: ⅜" drill bit



Summit Lathe*	
Model	16X80B
S/N	38331
Inserts	Carbide-tipped

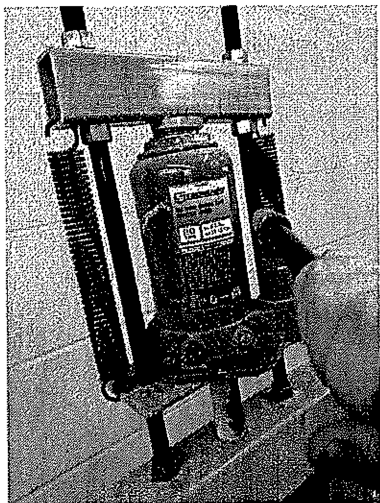
Figure 8. Used to reduce the nominal diameter of the shaft to desired dimension.



Clausing Lathe*	
S/N	51223

Figure 9.

Held shaft in place as internal thread was made

	Hydraulic Press and Bottle Jack	
	Capacity	20 ton
	Figure 10. Used to press the shaft into the plate	

Auxiliary Equipment

- Dial Caliper:
    - Min. Measurement Dimension: 1/1000"
- File: Used to chamfer edges.
- File card: Used to clean file after use.
- Feeler gage: Used to zero the handwheel' dial for the milling machine and lathe.
- 3-piece ¼" x 20 Thd tap set: Use to thread inside of the ¼" diameter hole on shaft.
- Punching kit: Use to engrave the semester and the names of the group members.
- Ball-peen hammer: Use to apply pressure for engraving the letters.

* The velocities that were used for each machine can be founded in Appendix A-1.

PROCEDURE:

Material cutting

1. A band saw was used to cut a 3" wide long flat bar to a length of 3.2".

2. The same equipment was used to cut a 1" diameter round stock bar to a length 2.75".

belt sander

3. A sand belt was used to remove remaining material on the edges of the plate and round stock left from the cutting process.

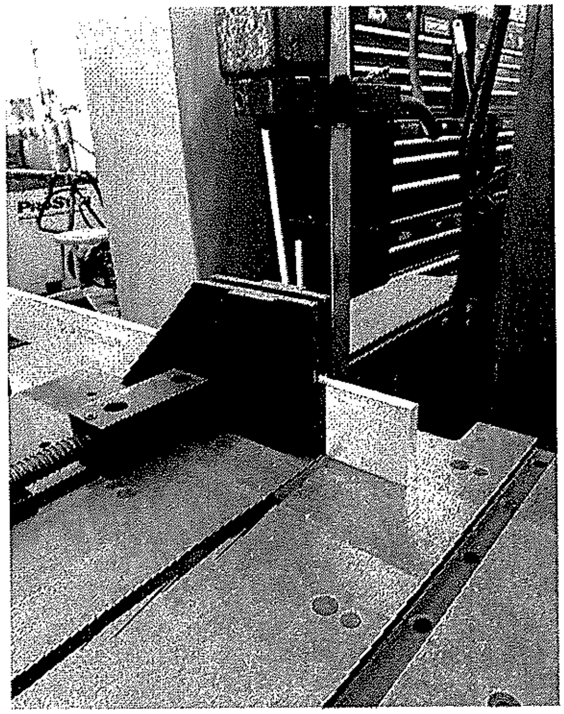


Figure 11. MetalMizer band saw cutting the 3" flat bar.

Plate Machining

1. The plate was set in the Enco milling machine. End mill velocity was 200 RPM.
2. The 3.2" x 0.5" sides of the plate were faced off before machining began.
3. The 3.2" length side of the plate was milled to 3.00" (± 0.005"). (See Figure 12)
4. One 3.00" x 3.00" side of the plate was sprayed with blue paint.
5. The blue side of the plate was scribed with the center lines for the four ⅜" and one ¼" diameter holes, according to measurements and indications in lab guide. (See Figure 13)
6. The plate was set in the Bridgeport milling machine. Velocity was set to 200 RPM.

7. A center drill was used to make an initial indentation for the holes at the intersections of scribed marks.
8. The center drill was replaced by a drill bit. A ⅜" diameter hole was drilled all the way through the plate. The procedure was repeated for each of the four ⅜" holes. (See Figure 14)
9. The ¾" diameter end mill drill bit was used to drill the hole all the way through the center of the plate.
10. The dimensions and locations of the four ⅜" diameter holes were tested by placing one ¼" bolt in each of them and attaching the plate to a mold. (See Figure 15)
11. The diameter of the hole on the center of the plate was measured to calculate the diameter of the shaft needed according to the desired interference.

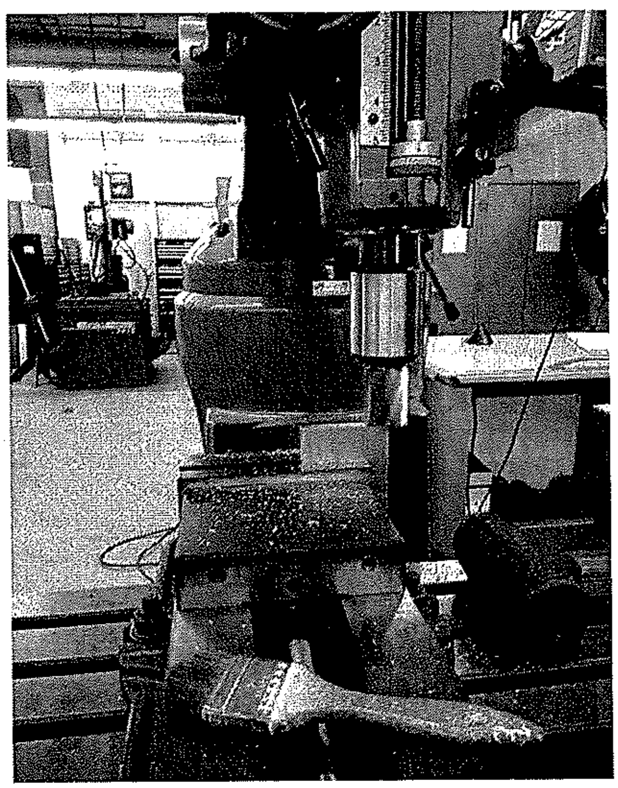


Figure 12. Milling machine removing material from 3.00" x 0.5" side of plate.

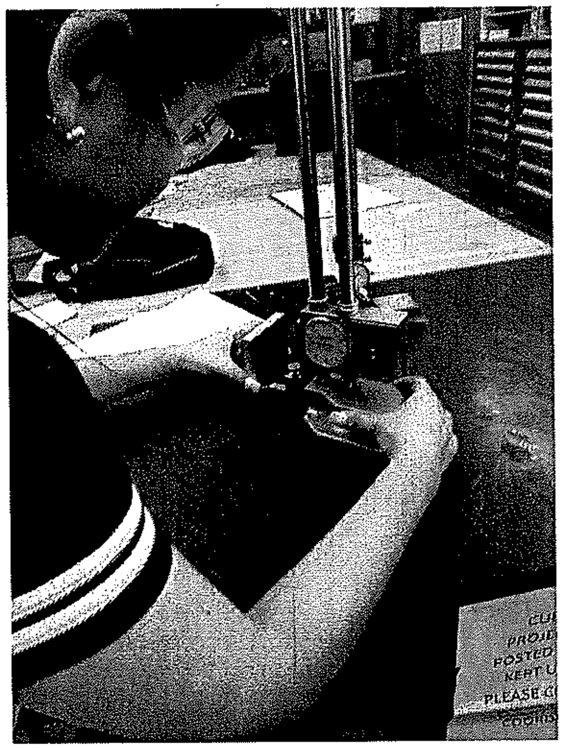


Figure 13. The scribe being used to mark surface of plate. Holes will be drilled where lines intersect.

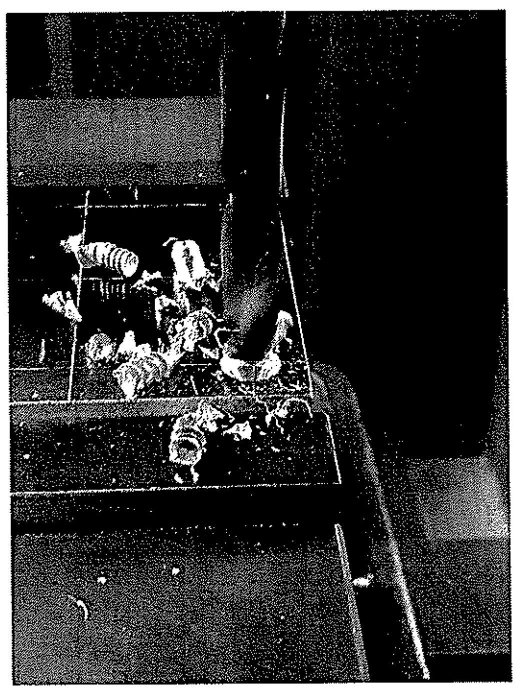


Figure 14. A ⅜" diameter hole is being drilled all the through the plate.

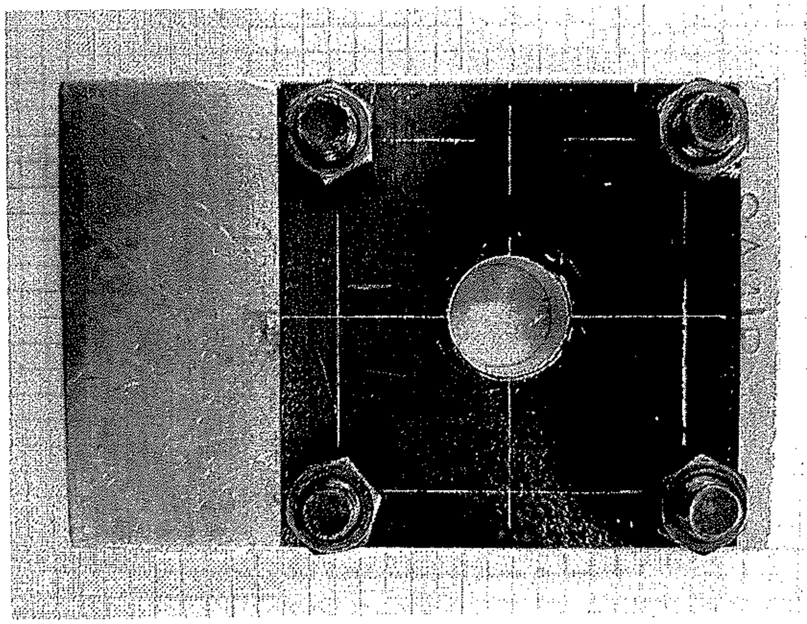


Figure 15. A mold was used to test the dimensions of the plate.

L test rig

Shaft Machining

1. The 2.75" long piece of round stock bar was set in the Summit lathe (400 RPM).
2. One side of the shaft was faced off, and had its edge chamfered to a 45° angle. Then, the remaining side of the shaft was faced off. (See Figure 16)
3. The shaft was machined to a 2.50" (± 0.005") length.
4. The diameter on one side of the shaft was reduced to a 0.759" diameter by a ½" length. (See Figure 17)
5. Then, the edge was chamfered to a 45° angle.
6. The shaft was set to the Clausing lathe with a 180 RPM velocity.
7. A 7-HSS drill bit was set on the tailstock to drill through center of the 1" diameter side to ¾" length.
8. A ¼"-20 Thd. tap kit was used to thread the hole through all its length. (See Figure 18)

9. The ¼" diameter threaded hole was tested by inserting a ⌀ ¼" x ¾" round screw. (See Figure 18)

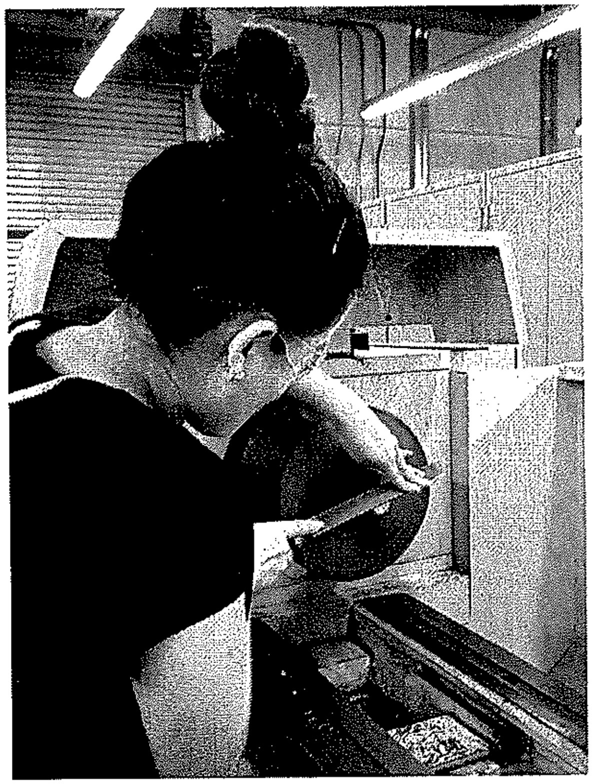


Figure 16. The edge 1" diameter side of the shaft is being chamfered with a file at a 45° angle.

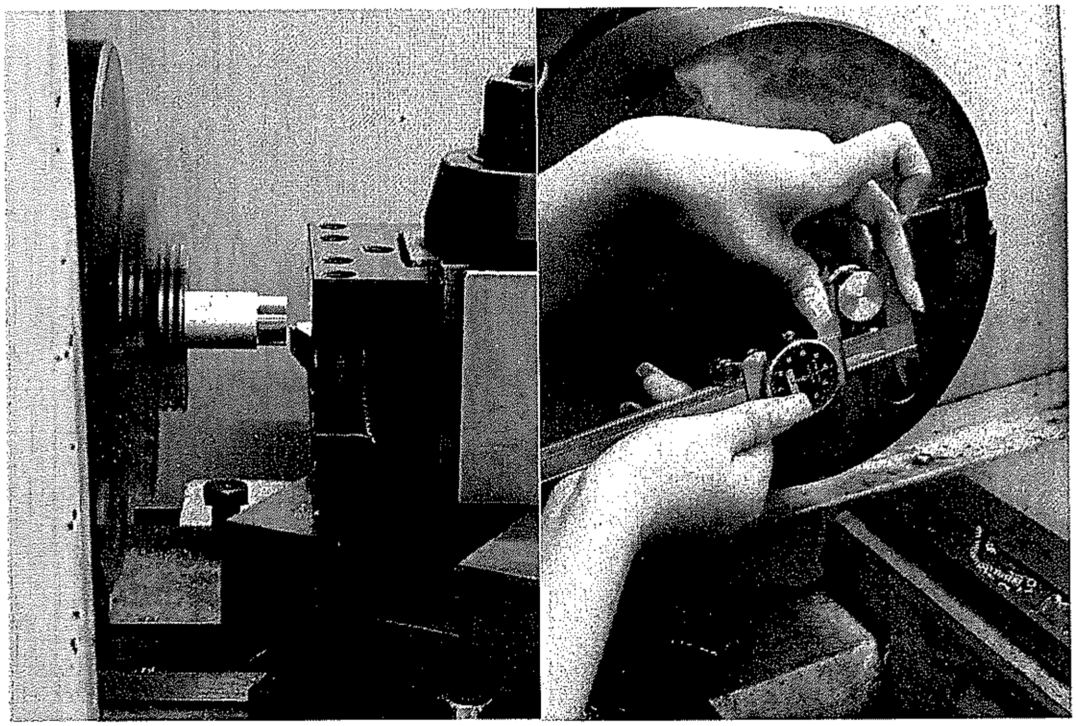


Figure 17. The diameter of one side of the shaft is being machined in the Summit Lathe.

(a) (b)

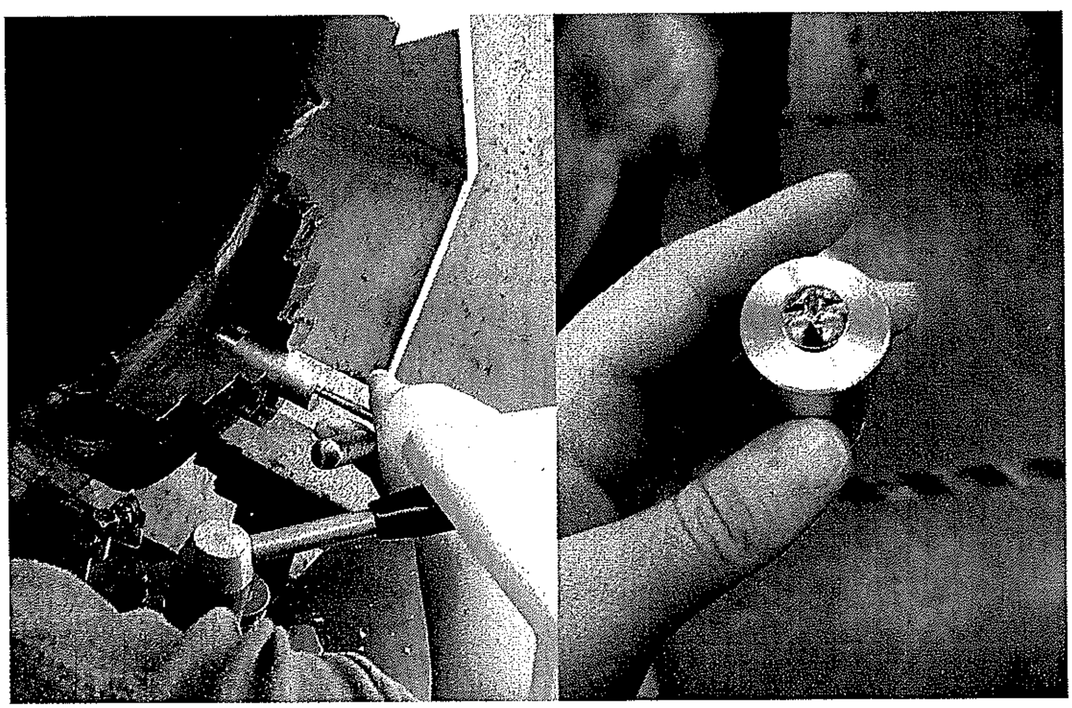


Figure 18. The right picture shows the use of the ⌀ ¼" - 20 Thd. tap kit. The left side shows a ⌀ ¼" round head bolt used to test the hole after tapering was complete.

(a) (b)

tapping

Assembly

1. A press of 20 ton of capacity was used to insert the 0.759" diameter side of the shaft into the center hole of the plate. (See Figure 19)
2. The assembly was set in the Enco milling machine, with a 200 RPM velocity.
3. A 0.625" (± 0.005") length by 0.156" (± 0.005") height notch was machined at the end of the 1" diameter side of the shaft.
4. The assembly was attached to a 1ft lever with a 1.1 lb_f hanger and a 10 kg disk attached to the end. (See Figure 20)
5. Finally, a punching kit and a ball-peen hammer were used to stamp the semester and the names of the group members. (See Figure 21)

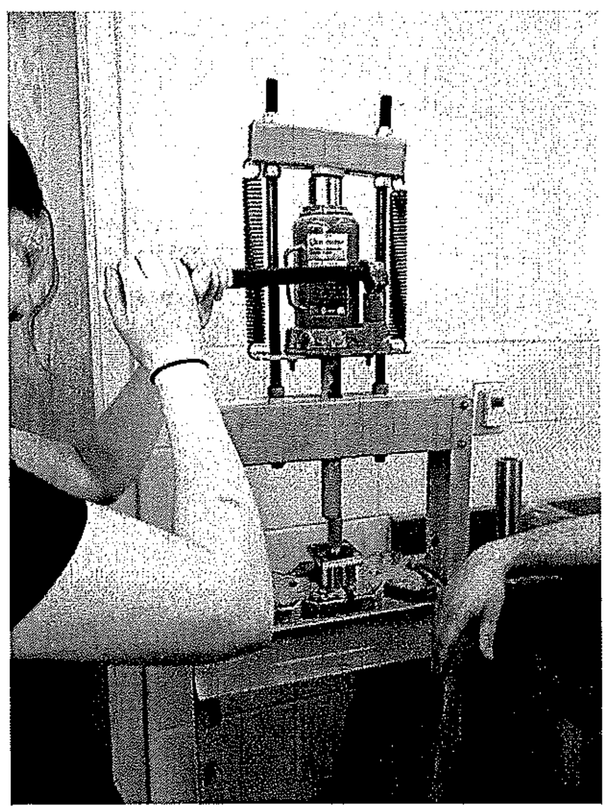


Figure 19. The 20-ton press was used to press the shaft into the plate.

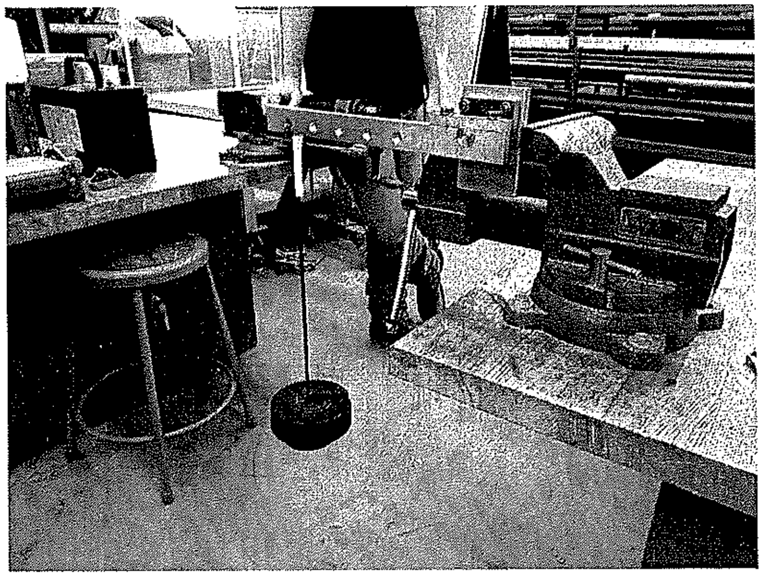


Figure 20. Assembly being tested by hanging a ~~10~~ 5 kg disk by the end a 1 ft lever.

Figure 21. Final assembly with the semester and names of the group member engraved.

DATA:

	Ave. Shaft Diameter (in)	Ave. Hole Diameter (in)	Interference (in)	Torque (ft-lb_f)
Measured Values	0.769	0.759	0.010	12.1

Table 1. Presents the values measured from machined assembly

An average of the shaft and hole diameters was calculated from a series of measurements taken. The torque was converted from kg_f to lb_f using the conversion factor
m

$$1\ kg_f = 2.20\ lb_f$$

m

The interference was found by subtracting the average hole diameter from the average shaft diameter.

SAMPLE CALCULATIONS:

See appendix A-2 for Sample Calculations. Equations used in this section came from Budynas [1] and Kalpakjian [3].

RESULTS:

	Specifications For h7/S6 interference		Measurements
	Min. Values	*Max. Values*	
Shaft Diameter, d (in.)	0.7514	0.7519	0.769
Hole Diameter, D (in.)	0.7500	0.7508	0.759
Interference, δ (in.)	0.0006	0.0019	0.0100
Contact Pressure, P (psi)	3556	11260	329
Force, F (lb_f)	4189	13260	387
Torque, T (ft-lb_f)	131	414	12.1

Table 2. Comparison of Specified and Measured Dimensions.

DISCUSSION and ANALYSIS:

The minimum tolerance of the shaft was calculated to be 55×10^{-6}in. This value is too small to be within reach of the machines ? available. It was recommended by the instructor to attempt an interference of 0.003" - 0.005". The actual interference attained was 0.0100", falling outside of the tolerance range. Rather than risking the shaft being too small for an interference fit, it was decided that the shaft should be left as it was.

One of the requirements of this lab was for the contact pressure of the maximum possible torque to be less than the value of yield strength for the material. The specifications of the assembly met this requirement (Table 3). The actual contact pressure, however, did not. The contact pressure, calculated from the assembly's interference, was far greater than the material's yield strength.

Theoretical Contact Pressure, P_{max} (ksi)	Yield Strength, s_y (ksi)	Actual Contact Pressure, P (ksi)
11.3	40.0	59.2

Table 3. Comparison of theoretical maximum contact pressure and material's yield strength. See Sample Calculations.

Though the interference was too large, no cracks appeared when the shaft and hub were press fit together. This absence could be due to the ductility of the material. The contact pressure of the assembly surpassed the ultimate strength of material as well. Aluminum 6061-T6 has an ultimate tensile strength of 45 ksi [4]. Though the contact pressure was larger than the ultimate tensile strength, the assembly did not fail. The hole and shaft have suffered permanent deformation and, if separated, would not return to their original diameter. If the assembly has sustained plastic deformation, then it is possible that the interference value has changed. A change in the interference value would lead to different values for friction force, contact pressure, and bearable amount of torque.

The speeds used to machine this assembly were all relatively slow[2] which caused the surface finish to be rougher than industry standards. One of the purposes of this lab was to become familiar with the instruments available, making slower speeds more practical.

CONCLUSIONS:

Since the two-part assembly built passed the test and was able to withstand a 10 ft-lb_f torque applied at the end of the shaft without turning, the purpose of the lab was achieved. From this, it could be concluded that the range of interference between the shaft and the hole was

[2] See appendix A-1

correct and able to secure the two pieces together. However, it sustained more contact pressure than anticipated.

During this experiment, students familiarized themselves with the shop, learned how to operate and take care of the machines and followed safety measures such as the use of safety glasses, long hair had to be tied back, etc. As future engineers, this lab was extremely helpful since it gave students an introduction to machining processes. By completing this lab, the authors of this report have been trained in the operations of subtractive manufacturing.

REFERENCES:

[1] Budynas R. G., and Nisbett J. K., 2010, *Shigley's Mechanical Engineering Design*, 9th edition, McGraw-Hill.

[2] Carlson, R., "Tolerance Assigning, Machining and Testing of a Two-Part Assembly", 22 January 2018.

[3] Kalpakjian, S., and Schmid, S. R., 2014, *Manufacturing Engineering and Technology*, 7th edition, Pearson.

[4] "Aluminum 6061-T6; 6061-T651," ASM Material Data Sheet [Online]. Available: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6. [Accessed: 20-Feb-2018].

APPENDICES:

A-1: Machine Speeds

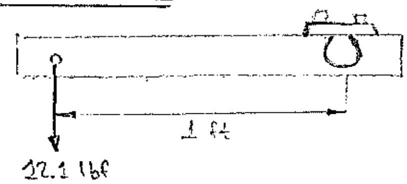
MACHINE		**SPEED**	
Type	***Model***	***Linear (FPM)***	***Rotational (RPM)***
Band Saw	MetalMizer	275	-
Milling Machine	Enco	-	200
Milling Machine	Bridgeport	-	200
Lathe	Summit	-	400
Lathe	Clausing	-	180

Table 4. Lists the speeds to which each machine was set.

1) Required Shaft Tolerance

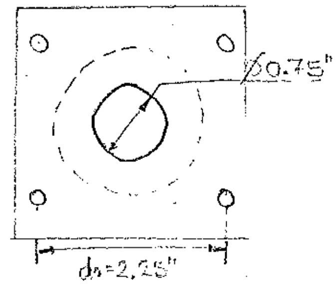
$E = 10 \cdot 10^6$ psi
$S_y = 40{,}000$ psi

Lever:



$d_i = 0$
$d = 0.75''$
$d_o = 2.25''$

Plate:
thickness = 0.5"



Torque:

$$T = W\ell = (12.1 \text{ lbf})(12 \text{ in}) = 145.2 \text{ in-lbf}$$

Force:

$$F = \frac{T}{d/2} = \frac{145.2 \text{ in-lbf}}{\frac{0.75 \text{in}}{2}} = 387.2 \text{ lbf}$$

Pressure

$$P = \frac{F}{A} = \frac{F}{\pi d (\text{thickness})} = \frac{387.2 \text{ Lbf}}{(\pi)(0.75'')(0.5'')}$$

$$P = 328.7 \text{ psi}$$

Interference / shaft tolerance:

$$\delta = \frac{2Pd^3}{E}\left[\frac{(d_o^2-d^2)(d^2-d_i^2)}{d_o^2-d_i^2}\right]^{-1}$$

$$\delta = \frac{2(328.7 \text{ Lb/in}^2)(0.75\text{in})^3}{10 \cdot 10^6 \text{ Lb/in}^2}\left[\frac{[(2.25\text{in})^2-(0.75\text{ in})^2](0.75\text{in})^2}{(2.25\text{in})^2}\right]^{-1}$$

$$\delta = 0.000055 \text{ in}$$

This is the minimum interference the fit can have, so the assembly does not fail.

2) Theoretical Min, Max Torque Calculation

When both members (shaft and hub) are the same material:

$$P = \frac{E\delta}{2d^3}\left[\frac{(d_o^2 - d^2)(d^2 - d_i^2)}{d_o^2 - d_i^2}\right]$$

$E = 10 \times 10^6$ psi

$d_i = 0$
$d = 0.75"$ → Nominal shaft diameter
$d_o = 2.25"$

Tolerance: H7-s6 (Tables A-13, A-14)

Lower deviation → $\delta_\ell = \delta_f$ = fundamental deviation
Upper deviation → $\delta_u = \underbrace{\delta_\ell}_{\text{Lower deviation}} + \underbrace{I.T.}_{\text{Tolerance grade}}$

Hole:
$\delta_\ell = 0$
$\delta_u = IT7 = 0.0008"$
→ $D_{min} = 0.75"$, $D_{max} = 0.7508"$

Shaft:
$\delta_\ell = \delta_f = 0.0014"$
$\delta_u = \delta_\ell + IT6 = 0.0019"$
→ $d_{min} = 0.7514"$, $d_{max} = 0.7519"$

Interference:

$\delta_{min} = d_{min} - D_{max}$
$= 0.7514" - 0.7508" = 0.0006"$

$\delta_{max} = d_{max} - D_{min}$
$= 0.7519" - 0.7500" = 0.0019"$

Pressure

$$P_{min} = \frac{E\delta_{min}}{2d^3}\left[\frac{(d_o^2 - d^2)(d^2 - d_i^2)}{d_o^2 - d_i^2}\right]$$

$$= \frac{(10E6\ Lb/in^2)(0.0006\ in)}{2(0.75\ in)^3}\left[\frac{[(2.25\ in)^2 - (0.75\ in)^2](0.75\ in)^2}{(2.25\ in)^2}\right]$$

$P_{min} = 3,555.56$ psi

$$P_{max} = \frac{(10E6\ Lb/in^2)(0.0019\ in)}{2(0.75\ in)^3}\left[\frac{[(2.25\ in)^2 - (0.75\ in)^2](0.75\ in)^2}{(2.25\ in)^2}\right]$$

$P_{max} = 11,259.3$ psi

Force:

$$F_{min} = PA = P \pi d (\text{thickness}) = \left(355[illegible] \frac{lb}{in^2}\right) \pi (0.75 \text{ in})(0.5 \text{ in})$$

$$F_{min} = 4{,}188.8 \text{ lbf}$$

$$F_{max} = (11{,}259.2 \text{ psi}) \pi (0.75 \text{ in})(0.5 \text{ in})$$
$$= 13{,}264.5 \text{ lbf}$$

Torque:

$$T = F \times r = F \times \frac{d}{2}$$

$$T_{min} = (4{,}188.8 \text{ lbf})(0.375 \text{ in})\left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 130.9 \text{ ft-lbf}$$

$$T_{max} = (13{,}264.5 \text{ lbf})(0.375 \text{ in})\left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 414.5 \text{ ft-lbf}$$

Material Removal Rate (Band saw):

$$MRR = Vel_f \times \underbrace{W}_{Kerf} \times Th'k$$

* Assumptions

thickness: $\frac{1}{2}$ in $= 0.5$ in

$Vel_f = 4.8 \frac{ft}{min}$

$Kerf = \frac{1}{8}$ in $= 0.125$ in

$$\Rightarrow MRR = 4.8 \frac{\cancel{ft}}{min} \times 0.125\,in \times 0.5\,in \times \frac{12\,in}{1\,\cancel{ft}}$$

$$\boxed{MRR = 3.6 \frac{in^3}{min}}$$

Material Removal Rate (milling):

$$MRR = wdv \quad \ldots (I)$$

where,

w = thickness of plate $= 0.5$ in

d = depth of cut =

v = feed rate of the work piece $= fNn \quad \ldots (II)$

*Assumptions

We are analyzing a pass with a depth of cut of 0.030in ($d = 0.030$in) by using the table 24.2 in our book for aluminum material uncoated cutting tool, the feed (f) is $0.009 \frac{in}{tooth}$.

$\Rightarrow$ By replacing values in (II),

$$v = fNn$$

$$v = 0.009 \frac{in}{\cancel{tooth}} \times 200\,rpm \times 8\,\cancel{tooth} = 14.4 \frac{in}{min}$$

$\Rightarrow$ By replacing values in (I),

$$MRR = wdv$$

$$MRR = 0.5\,in \times 0.030\,in \times 14.4 \frac{in}{min} = 0.216\,in^3/min$$

$$\boxed{MRR = 0.216\,in^3/min}$$

Material Removal Rate (drilling):

$$MRR = \left(\frac{\pi D^2}{4}\right) f N$$

where,

D = Diameter of drill

f = feed

N = Rotational speed

*Assumptions

We are analyzing the drill of a 3/8 in diameter hole. ($D = 3/8$ in), N would be 200 rpm because that's how the machine was set. Finally, according to table 23.12, $f = 0.008\ in/rev$

$$\Rightarrow MRR = \left[\frac{\pi\left(\frac{3}{8}in\right)^2}{4}\right] \times 0.008 \frac{in}{rev} \times 200 \frac{rev}{min}$$

$$\boxed{MRR = 0.177 \frac{in^3}{min}}$$

Material Removal Rate in a turning operation (lathe):

$$MRR = \pi D_{avg} \times d \times f \times N$$

where,

D_{avg} = average diameter

d = depth of cut

f = feed

N = Rotational speed

* Assumptions

We are analyzing the first pass made to reduce the diameter of the shaft. The initial diameter (D_o) is 1 in, the depth of cut (d) is 0.020 in, f was obtained from the table 23.4 in the textbook for aluminum alloy TiN-coated carbide, in which $f = 0.018 \frac{in}{rev}$ and N = 180 rpm, $D_{avg} = \frac{D_o + D_i}{2} = D_o - d = 0.980$ in

$$\Rightarrow MRR = \pi D_{avg} \times d \times f \times N$$

$$MRR = \pi \times 0.980\ in \times 0.020\ in \times 0.018 \frac{in}{rev} \times 180 \frac{rev}{min}$$

$$\boxed{MRR = 0.120 \frac{in^3}{min}}$$